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(54) Abstract Title
Thickness meter for thin transparent objects

(57) A thickness meter uses a single fibre confocal method for direct measurement of the distance between the focal points of the beam on the top and bottom surfaces of a lens 30 or object being measured. A light source transmits illumination down an optical fibre 14 to a movable focussing head 18, which focusses the illumination from the end of the fibre onto the object to be measured, and focusses illumination reflected from the object back to the end of the fibre. The end of the fibre 16 thus acts as the pinhole aperture for the confocal effect. A directional coupler 12 is located in the optical fibre, for diverting illumination reflected from the lens or specimen to a detector. This detector detects the maxima which occur as the focal point passes through the surfaces of the object, and the object thickness is calculated therefrom.

FIG. 1A

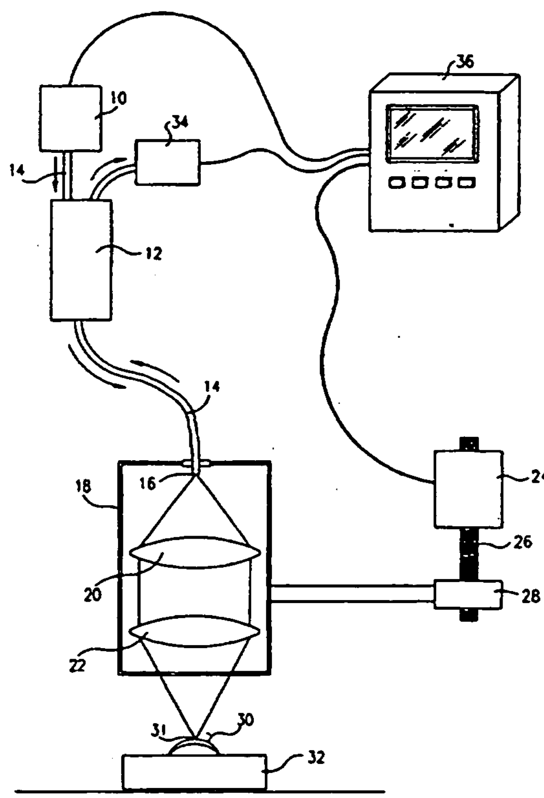

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FIG. 1A

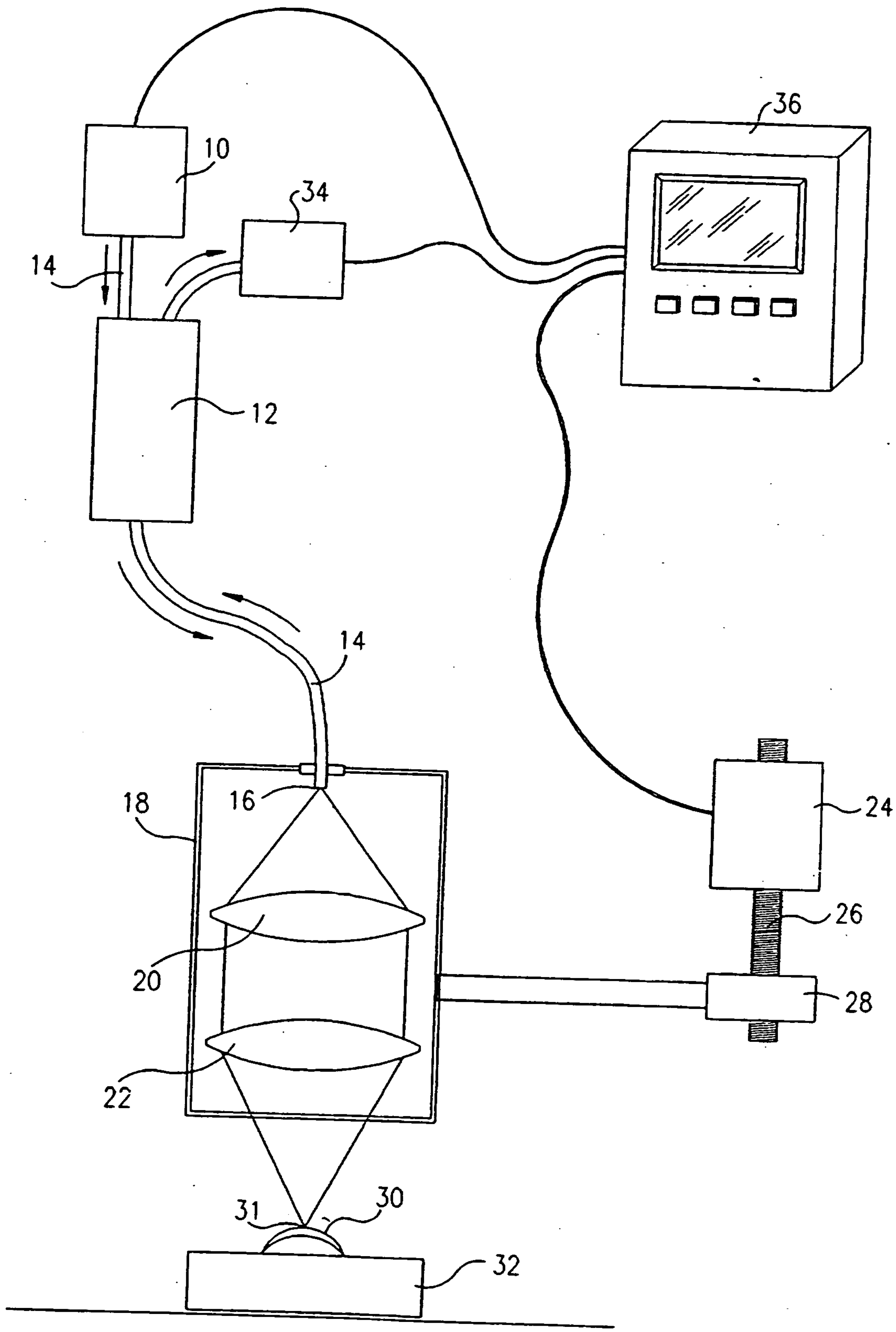


FIG. 1B

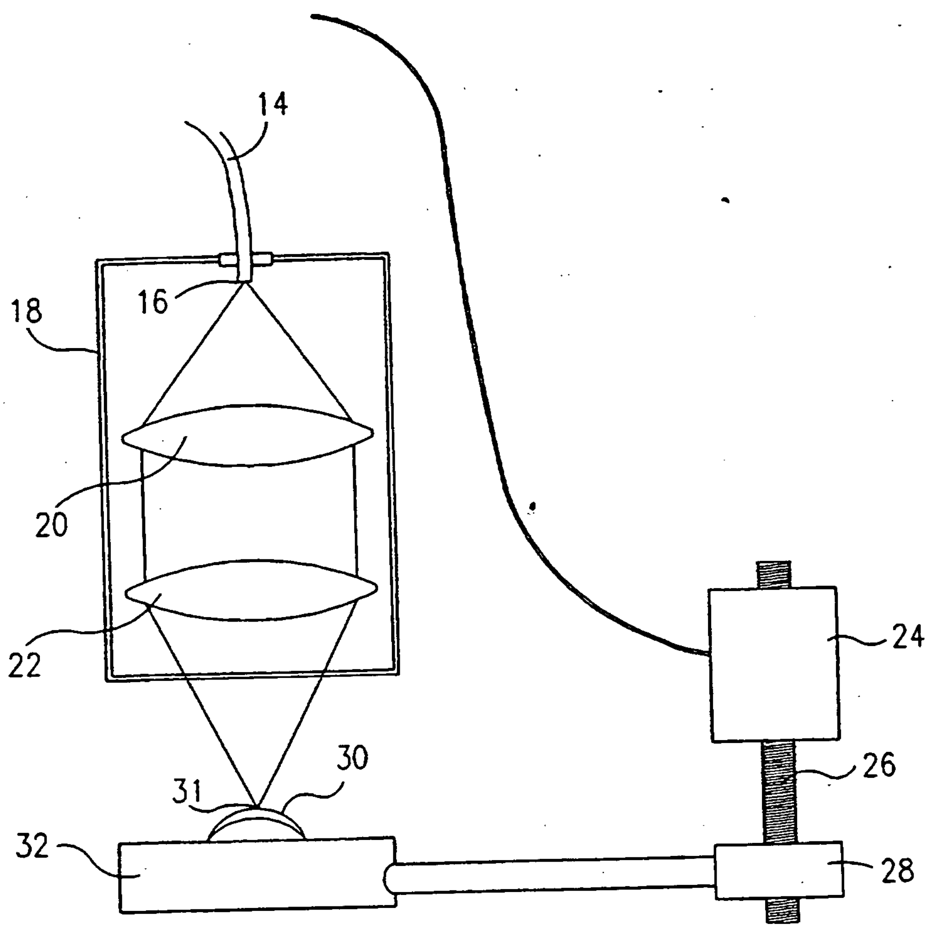


FIG. 2

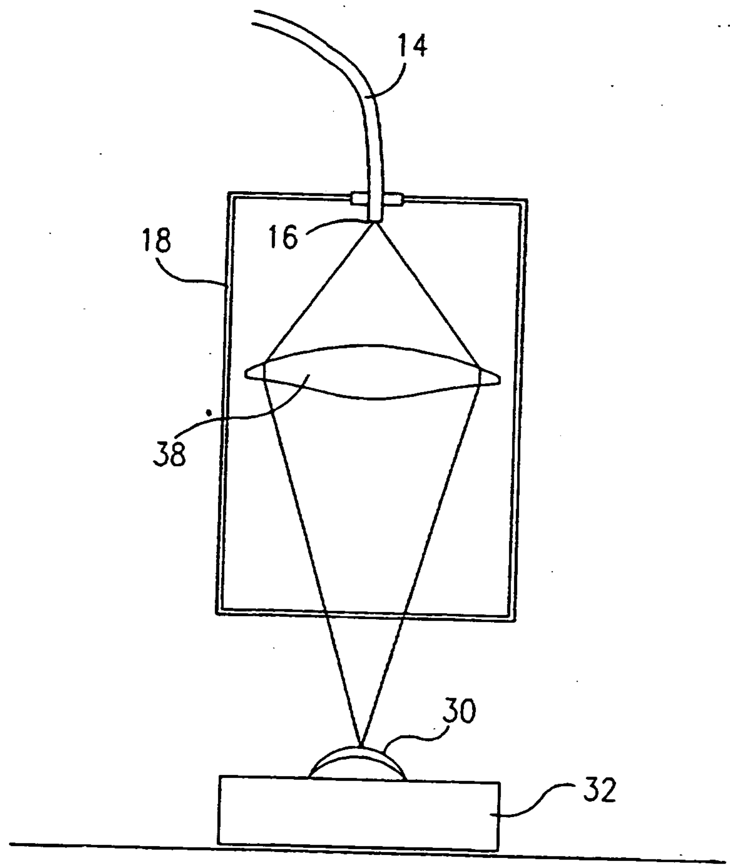


FIG. 3

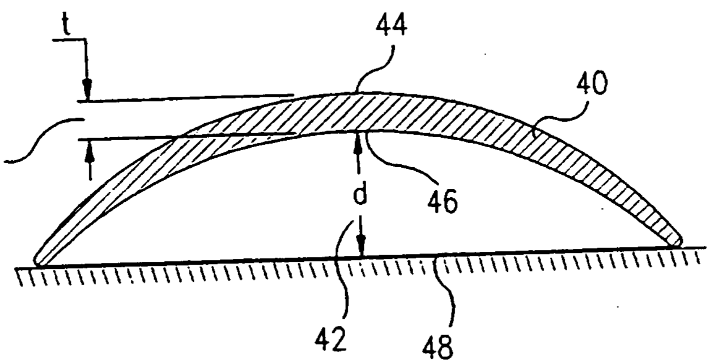


FIG. 4A

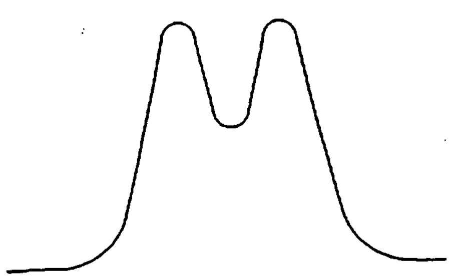


FIG. 4B

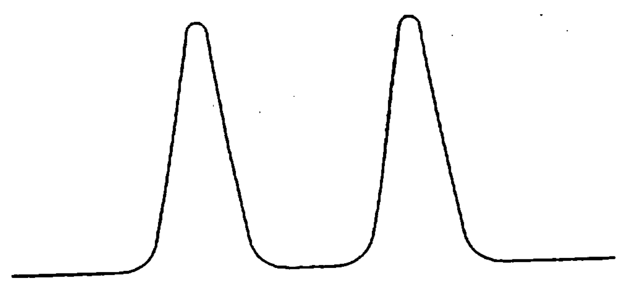
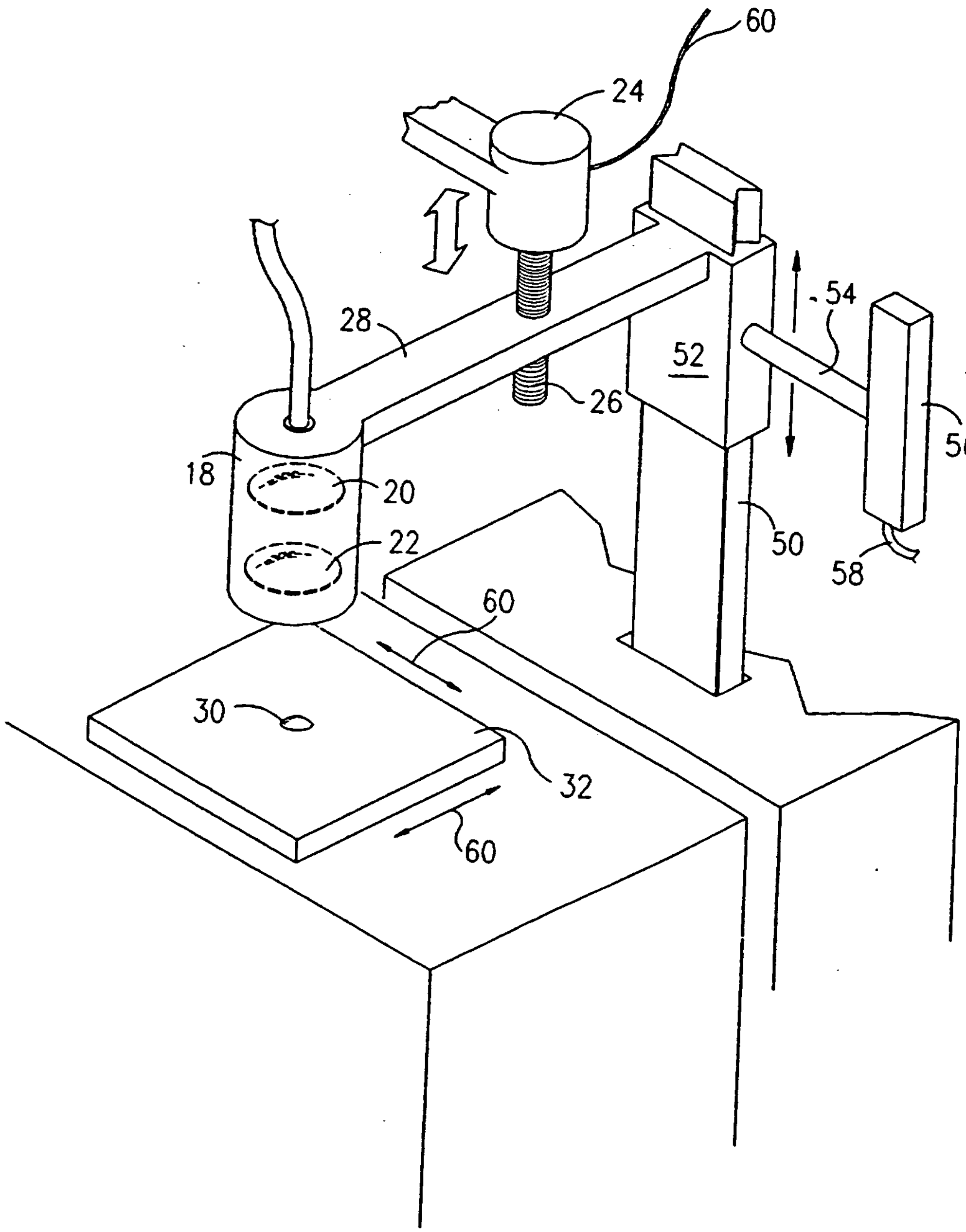


FIG. 5



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THICKNESS METER FOR THIN TRANSPARENT OBJECTS

The present invention relates to the field of instrumentation for making non-contact thickness measurements of thin transparent objects, and particularly of contact lenses.

The measurement of the thickness of thin transparent objects in a non-contact manner is problematic. The methods generally used for remote length measurements are mostly optical measurements, such as interference methods, time of flight methods, triangulation methods, conoscopic holographic methods, and dynamic focus methods. These methods work well for determining the distance to opaque objects, where the surface of the object is easily picked up, but not for thickness measurements of transparent objects, because of the difficulty of defining the bottom surface optically. Other methods such as ultrasonic, RF or microwave methods are very limited in their accuracy for thin objects, because of the comparatively long wavelength of the probe energy used.

Contact lenses are thin transparent objects, whose thickness is measured in a variety of situations, ranging from quality control measurements in the lens manufacturing plant, to the checking and measuring of the lenses of customers in the High Street ophthalmic shop. Because of their small size and delicate construction, the measurement of the thickness, profile and sagittal bow of contact lenses is even more difficult than for the general thin transparent object as mentioned above. The measurement becomes even more difficult with the modern hydrated soft lenses, such as those known as hydrogel or soft lenses. Such measurements need to be speedy, accurate, of low cost and without danger of damage to the lens under test.

There are a number of instruments known in the prior art and currently used for measuring the thickness of contact lenses. The majority of these instruments require mechanical probing of the lens, with its incumbent danger of damage to the lens.

Furthermore, since the lenses are not flat, such mechanical methods generally require the use of delicate and complex holding mounts for centering the lens for measurement, which makes mounting of the lens comparatively slow, and is also liable to cause damage. In addition, the lenses often have to be measured when they are wet, which makes handling, mounting and measuring with the mechanical systems more difficult.

The most popular of such instruments is the Optimec, manufactured by Eurolent Accesorios, of Madrid, Spain. In order to measure the lens thickness using this instrument, the lens is mounted with its position defined by means of a mechanical probe. A highly magnified side projection view of the mounted lens with a measurement scale superimposed, then allows the central thickness to be measured visually.

Another instrument in use is the Rehder gauge, which provides for an automatic measurement. Though this instrument uses a non-contact method, and is accurate, it is comparatively expensive and is thus unlikely to find widespread popular use.

There therefore exists a need for a low cost, fast, accurate and easy-to-use non-contact method for measuring the center thickness, sagitta and surface profile of contact lenses. There is also a need for a simple, non-contact and accurate method for measuring the thickness of thin transparent objects in general.

The present invention seeks to provide an improved contact lens thickness and surface profile meter, which overcomes the disadvantages and drawbacks of prior art instruments. The present invention further seeks to provide a non-contact method and instrument for measuring the thickness of thin transparent objects in general. The invention uses an optical fiber confocal measurement, which makes it compact, accurate, robust and inexpensive.

The confocal method was devised for use in the confocal microscope, in which the illumination is focused to a single point on the object to be viewed, and only the light reflected or scattered from that point is used in forming the image. This is achieved by focussing the incident illumination through a small pinhole aperture before it is collimated and focussed on the specimen surface, and then causing the reflected or

scattered light from the specimen to pass through the same pinhole aperture on its way to the detector. Only when the surface of the object is exactly in focus, will a maximal part of the light beam reflected or scattered off it be transmitted to the detector. The focal plane can be aligned at the surface of the object, or within its volume, thus allowing imaging of any part of the object.

The lateral resolution of a confocal microscope is somewhat better than that of a conventional microscope, and the axial resolution considerably better. The image definition is sharper, since the depth of field is much reduced, and out-of-focus signals and interference are thus much reduced. In order to obtain a full image of the object, the object or the microscope objective can be scanned in all three directions, depending on the object view required.

Though the original confocal microscopes used free space propagation of the illumination, a number of confocal microscopes have been described recently in the prior art, in which an optical fiber is used to convey the incident beam to the objective lens, and to return the reflected or scattered light from the objective to the detector. When this is done, the end of the fiber acts as the pinhole aperture, both for the incident and for the reflected light. This arrangement ensures robust construction and good mechanical stability. These confocal microscopes have been designed and used with the intention of providing high resolution imaging of samples, and are consequently complicated in structure and expensive to produce.

In U.S. Patent No. 5,120,953, to M. R. Harris, is described a scanning confocal epi-illumination microscope, using a single fibre for transmitted and returned paths of the illumination. The microscope has been designed with particular emphasis on the use of the fibre delivery to allow a large spatial separation of the illumination and detection systems from the objective head. The inventor uses this aspect of his invention to describe a compact objective head for high resolution endoscopic microscopy for medical applications.

In U.S. Patent No. 5,161,053 to T. P. Dabbs, is described a confocal microscope for conventional use, of similar structure to that of Harris. This invention is particularly concerned with providing the optimum imaging performance possible from such a microscope, and therefore limits itself to the case of diffraction limited illumination and imaging optics. The inventor also proposes the use of polarisers to increase the contrast

and definition, by discriminating against the light scattered from the sample as compared with the light reflected therefrom.

In U.S. Patent No. 5,491,550 also to T. P. Dabbs, the inventor describes a confocal interference microscope for measuring, inter alia, the path length between two locations in a sample. Since it is an interference microscope, it necessitates the use of a substantially coherent and monochromatic source of illumination. Furthermore, the interference measurement dictates the use of reference and signal channels, all of which makes the instrument complex, expensive and non-trivial to use. Emphasis is laid on providing maximum resolution in the instrument, making it suitable for very high resolution measurements down to sub-micron levels, such as, in the words of the inventor, the inspection of microchips, the measurement of the thickness of monolayer sheets of packaging materials, biological cellular dimensions, and others. These particular features, and others, make this instrument over-sophisticated for use in an application such as the measurement of the thickness of contact lenses.

The thickness meter according to the present invention uses a single fibre confocal method for direct measurement of the distance between the focal points of the beam on the top and bottom surfaces of the lens or object under test or being measured. Since no qualitative imaging functions have to be performed by the optical system, the instrument does not require the diffraction limited optics needed by the confocal microscopes described in the prior art. The optical design can thus be simple and the optics inexpensive to produce, commensurate with it being of sufficient quality at the working distance and depth of focus required. Furthermore, since the instrument does not use an interference method of measurement, the system construction is very simple and only a single reading is required to define each measurement position. Since the instrument uses an optical method, no mechanical contact with the sample under test is necessary. Since the lens measurement is made with the lens simply sitting on the measurement table, there is no need for complicated lens mounting fixtures. Furthermore, the method can be highly automated such that the measurement can be performed easily and quickly. The invention is, in the main, described in terms of the contact lens thickness meter, as a specific embodiment of a thickness meter for thin transparent objects in general. It is to be understood that the same principles of measurement are applicable also for the general case, with the necessary changes in constructional details for different types of thin transparent objects.

There is thus provided, in accordance with a preferred embodiment of the present invention, a light source which transmits illumination down an optical fibre to a focussing head. The focussing head is operative to focus the illumination from the end of the fibre onto the contact lens to be measured, and to focus illumination reflected from the lens back to the end of the fibre. The end of the fibre thus acts as the pinhole aperture for the confocal effect. The lens or specimen to be measured is positioned on a table or other mounting surface below the focussing head, and means are provided for producing relative controlled motion between the focussing head and the lens or specimen to be measured. A directional coupler is located in the optical fibre, for diverting illumination reflected from the lens or specimen to a detector. This detector is operative to detect the maxima which occur as the focal point passes through the surfaces of the lens or specimen, causing illumination to be strongly reflected from that surface. An electronic unit then calculates and displays the thickness of the lens or specimen, taking into account the refractive index of the material. By making a measurement when the illumination is focussed on the lens support table, it is possible also to measure the saggital bow of a lens. If the support table is provided with means of orthogonal motion in the horizontal plane, then a complete surface scan profile of the lens can be plotted.

There is further provided in accordance with another preferred embodiment of the present invention a confocal thickness meter for thin transparent objects, such as contact lenses, including a source of illumination, an optical fibre having first and second ends, the illumination being coupled into the first end, a focussing head, fixed to second end of the fibre, operative to focus the illumination from second end of the fibre onto the object whose thickness is to be measured, and to focus illumination reflected from the object back to the second end of the fibre, apparatus for providing controlled relative motion between the object and the focussing head, along an axis in the direction of the focussed illumination, a detector to detect maxima in the level of the illumination on reflection from a surface of the object, a directional coupler disposed in the optical fibre for diverting illumination reflected from the object to the detector, and an electronic unit for calculating and displaying the thickness of the object.

In accordance with yet another preferred embodiment of the present invention, there is provided a confocal thickness meter for thin transparent objects, as described above, and additionally including mechanisms for providing controlled motion of the

object in two orthogonal directions in a plane substantially perpendicular to the direction of the illumination, such that the illumination beam is scanned over the surface of the object, thereby providing a plot of the surface profile of the object.

In accordance with still another preferred embodiment of the present invention, there is provided a confocal thickness meter for thin transparent objects as described above, and wherein the source of illumination is a laser diode.

There is further provided in accordance with yet another preferred embodiment of the present invention, a confocal thickness meter for thin transparent objects as described above, and wherein the second end of the fibre acts as a confocal pinhole aperture, from which illumination diverges into the focussing head, and onto which illumination reflected from the object is focussed.

There is also provided in accordance with further preferred embodiments of the present invention, a confocal thickness meter for thin transparent objects as described above, and wherein the focussing head contains either one convex lens for collimating illumination diverging from the end of the fibre and one convex lens for focussing the collimated illumination onto the object to be measured, or one aspheric convex lens for performing both of these functions.

There is even further provided in accordance with a preferred embodiment of the present invention, a confocal thickness meter for thin transparent objects as described above, and wherein the focussing head lenses are of cast or moulded manufacture.

In accordance with yet other preferred embodiments of the present invention, there is provided a confocal thickness meter for thin transparent objects as described above, and wherein the controlled relative motion between the object and the focussing head is provided either by movement of the focussing head, or by movement of the object, or by movement of both the object and the focussing head.

In accordance with a further preferred embodiment of the present invention, there is also provided a confocal thickness meter for thin transparent objects as described above, and wherein the controlled relative motion is executed by means of an electric motor.

In accordance with still more preferred embodiments of the present invention, there is provided a confocal thickness meter for thin transparent objects as described above, and wherein either the illumination is maintained at a substantially constant DC

level, and detection is performed by DC methods, or wherein the illumination is modulated, in which case detection of the signal is performed by means of synchronous or phase sensitive detection.

There is further provided in accordance with yet another preferred embodiment of the present invention, a confocal thickness meter for thin transparent objects as described above, operative to measure the thickness of contact lenses.

There is even further provided in accordance with a preferred embodiment of the present invention, a confocal contact lens meter, including a source of illumination, an optical fibre having first and second ends, the illumination being coupled into the first end, a focussing head fixed to the second end of the fibre, operative to focus the illumination from second end of the fibre onto the lens to be measured and to focus illumination reflected from the lens back to the second end of the fibre, apparatus for providing controlled relative motion between the lens and the focussing head along an axis in the direction of the focussed illumination, a detector to detect maxima in the level of the illumination on reflection from a surface of the lens, a directional coupler disposed in the optical fibre for diverting illumination reflected from the lens to the detector, and an electronic unit for calculating and displaying the thickness of the lens.

There is provided in accordance with still a further preferred embodiment of the present invention, a confocal contact lens meter, as described above and including a mounting surface on which is disposed the contact lens with its concave side facing the surface, and wherein the detector is used for detecting maxima in the level of the illumination on reflection from the concave surface of the lens and from the surface on which the contact lens to be measured is disposed, as the focussing head and surface are moved relatively, thereby enabling the electronic unit to calculate and display the sagitta of the lens

Furthermore, in accordance with yet another preferred embodiment of the present invention, there is provided a confocal contact lens meter, as described above and operative to measure a contact lens while immersed in a solution.

There is even further provided in accordance with a preferred embodiment of the present invention, a non-contact method for measuring the thickness of thin transparent objects, including the steps of transmitting illumination from a source by means of an optical fibre to a focussing head disposed so as to focus illumination from the end of the fibre onto the object, refocussing illumination reflected from a surface of

the object by means of the focussing head onto the end of the fibre which transmits the reflected illumination back up the fibre, diverting the reflected illumination by means of a directional coupler disposed in the fibre, onto a photo-detector for conversion into an electrical signal, moving the focussing head and the object relative to each other along an axis in the direction of the focussed illumination, and observing the relative positions of the focussing head and object when the detected signal shows the two maxima which occur as the focussed illumination moves through the top and the bottom surfaces of the object, and multiplying the difference between the relative positions by the refractive index of the object, to give the object thickness.

In accordance with yet another preferred embodiment of the present invention, there is provided a non-contact method for measuring the thickness of contact lenses, including the steps of transmitting illumination from a source by means of an optical fibre to a focussing head disposed so as to focus illumination from the end of the fibre onto the contact lens, refocussing illumination reflected from a surface of the contact lens by means of the focussing head onto the end of the fibre which transmits the reflected illumination back up the fibre, diverting the reflected illumination by means of a directional coupler disposed in the fibre onto a photo-detector for conversion into an electrical signal, moving the focussing head and the contact lens relative to each other along an axis in the direction of the focussed illumination, observing the relative positions of the focussing head and contact lens when the detected signal shows the two maxima which occur as the focussed illumination moves through the top and the bottom surfaces of the contact lens, and multiplying the difference between the relative positions by the refractive index of the contact lens, to give the contact lens thickness.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings, in which:

Fig. 1A is a schematic view of a contact lens thickness meter, constructed and operative according to a preferred embodiment of the current invention. Fig. 1B shows an alternative method of providing the relative motion between the focussing head of the present invention, and the lens under test.

Fig. 2 shows the structure of an alternative collimating and objective head for the contact lens thickness meter, in which the functions of the two individual lenses have been replaced by one aspheric lens.

Fig. 3 shows a typical contact lens on the measurement table, with the dimensions to be measured by the meter marked on the drawing.

Figs. 4A and 4B show different forms of output signals obtained from the detector, depending on the thickness of the lens being measured.

Fig. 5 is a view of the mechanical parts of the measuring table area of a contact lens thickness meter according to the present invention.

DETAILED DESCRIPTIONS OF PREFERRED EMBODIMENTS

Reference is now made to Fig. 1A which is a schematic view of a contact lens thickness meter, constructed and operative according to a preferred embodiment of the current invention. It is to be understood that the contact lens shown in this specific embodiment is typical of any thin optically transparent object or specimen. Though, for clarity in explaining the invention, the component parts are shown spread out and separate from the electronic unit, it should be understood that in a commercial implementation of the present invention, all of the parts would normally be built into one convenient enclosure.

The illumination source for the measurement is a laser diode 10, operating at 670nm. wavelength. The diode is coupled into a 9μ core fibre optical transmission line 14 for transmission to the focussing head 18, which can be remotely located from the source. The use of a fibre for light transmission also makes the connection flexible mechanically. The light for the measurement can be from any source, whether coherent or not, whether monochromatic or not, whether from an incandescent lamp, a vapour lamp, a discharge lamp, a solid state source such as a LED or a diode laser, or any other source. The only requirement is that the source have a wavelength output to which the system detector is sensitive, and a high enough luminous output to maintain a sufficient signal-to-noise ratio in the detected output signal. In the preferred embodiment described herein, a laser diode is used, largely for reasons of convenience, since laser diodes have a high output and are available with connections for easy coupling to the fibre optic line.

The focussing head 18 is located at the remote end 16 of the fibre optic transmission line 14. This head acts as the objective lens assembly for the optical imaging system, and contains a collimating lens 20 for collecting the light emitted from the end of the fibre 16. The collimated light is focussed by means of an objective lens 22 onto the surface 31 of the contact lens 30 to be measured, which is placed on the measuring table 32. The focussing head 18 can be moved up and down by means of an electric motor 24, which rotates a lead screw 26 which drives a support rod 28 attached to the focussing head. The motor drives the focussing head into the correct position when the incident light beam is focussed on the surface of the lens under test. If the motor 24 used is a stepping motor, then information about its position can be obtained either from the stepping pulse controller, or from a step encoder which may be an integral part of the motor. If the present invention is to be used for a general thickness measurement instrument, the mechanical clamping arrangements for the sample must be redefined accordingly.

The light reflected from the surface of the lens under test is refocussed by lenses 22 and 20 onto the fibre end 16, and is transmitted back up the fibre 14. A directional coupler 12 situated in the transmission line, diverts the reflected signal to a photo-detector 34, which converts the light signal into an electronic signal. The signal detection can be by a DC method, or if more sensitivity is required, by the use of an AC modulated light source, and phase sensitive detection techniques. Other modulation and detection coding may also be used. This electronic signal is inputted to the electronic control and display unit 36, together with a signal from the motor encoder which provides information about the position of the lead screw 26, and hence the position of the focussing head 18. The electronic unit 36 controls the motions, and, using the known refractive index of the lens material, calculates and displays the results of the measurement. The electronic unit also contains power supplies for the light source 10 and for the motor 24.

As an alternative to moving the focussing head, in a further embodiment of the present invention, the relevant parts of which are shown schematically in Fig. 1B, the focussing head 18 is fixed in position, and the measuring table 32 is moved vertically by means of a precision controlled motion mechanism, such as an electric motor 24, which rotates a lead screw 26 which drives a support rod 28 attached to the measuring table 32.

The lenses 20, 22 in the focussing head shown in Figs. 1A and 1B are conventional convex lenses. If the light source used is not monochromatic, they should preferably be achromatic in order to improve resolution and hence measurement accuracy. An alternative optical design for the focussing head, according to another preferred embodiment of the present invention, is shown schematically in Fig. 2. Instead of the double lens design, a single aspheric lens 38 is used as a transfer lens for projecting an image of the end of the optical fibre 16 onto the surface 44 of the contact lens being measured. The same lens also acts as the imaging lens for imaging the reflected light from the lens surface back onto the fibre end. The use of a single cast aspheric lens can reduce system cost and head size without affecting performance.

The meter uses the confocal principle for making an accurate measurement of the focal position of the illuminating spot on the lens surface. The "pinhole" for the confocal aperture is the end 16 of the transmission fibre. When the lens surface is in the confocal position, the reflected light beam focussed from the lens surface exactly falls on the fibre end 16, and the signal obtained is maximal. Very small movements away from the confocal position cause the signal to fall off very rapidly.

The measurement method is understood with the aid of Fig. 3 and Figs. 4A and 4B. Fig. 3 shows a contact lens 40 sitting on the measurement table. As the focussing head is moved vertically, from a position with the focal point of the system located above the top surface of the lens 44, to a position with the focal point of the system located below the bottom surface of the lens 46, a signal such as that shown in Fig. 4A is obtained. The first peak is obtained as the focal point passes through the top surface 44 of the lens, and hence provides a strong reflected signal to the detector, and the second peak is obtained as the focal point passes through the bottom surface 46 of the lens, and similarly provides a strong reflected signal. Measurement of the distance between the two peaks provides a measure of the optical thickness of the lens under test, and multiplication of this result by the known refractive index of the lens material yields t, the physical thickness 43 of the lens. If the lens is sufficiently thick, an output such as is shown in Fig. 4B is obtained, where the signal falls completely to zero between the peaks. This region is representative of the internal volume of the lens, from which virtually no signal is reflected or scattered back into the detector. If the lens is placed with its concave surface on the measuring surface, and a measurement is also made with the focal position of the illumination exactly on the surface of the

measurement table itself 48, it becomes possible to determine d, the sagittal bow 42 of the lens. In this way, the power and shape of the contact lens can be fully characterised speedily and with great accuracy.

Fig. 5 shows some mechanical details of the focussing head motion system of a contact lens thickness meter, constructed and operative according to another preferred embodiment of the present invention. In this embodiment, the support rod 28 of the focussing head 18 is attached to a saddle 52, which can move with great stability and accuracy along a ground finished V-groove slide 50. The motion itself is imparted, as in the previous embodiment shown in Fig. 1A, by an electric motor 24, powered and controlled from the electronic control unit by means of cord 60. In this embodiment, however, the motor can be a conventional AC or DC servo controlled motor, and the position of the focussing head is determined by means of a position transducer 56, which tracks the motion of the saddle 52 by means of a relay rod 54. The position signal is sent to the electronic control unit by means of signal cord 58. The position transducer 56 can be any convenient type, such as an LVDT transducer, a magnetic linear transducer, an optical ruled scale transducer, or any other suitable device for converting the mechanical position into an equivalent electronic signal.

The ease of mounting the lens is apparent from this drawing. Since the method is a non-contact method, there is no need for any mechanical clamping mechanisms to hold the lens, and it is generally sufficient to simply place the lens down flat in the correct position on the measuring table. Since the lens is sitting on a flat surface, a set of cross lines scribed on the table generally provides sufficient positional accuracy to ensure measurement near the centre of the lens, and there is thus generally no need for an accurate centring mechanism. Small deviations from the true centre of the lens will result in only small errors in the thickness measurement.

In a further embodiment of the present invention, controlled horizontal motion can be provided to the two orthogonal axes 60 of the measurement table, by means of standard motion slides attached to the two axes. By providing controlled horizontal scanning over the entire surface of the lens, it is possible to make a plot of the profile of the entire surface of the lens. In this way, lenses can be checked for imperfections which affect their power, and for variations in the designed thickness profile.

This contact lens thickness meter according to the present invention provides a solution to the problem of the measurement of solution-immersed contact lenses. Since

the refractive index of the solution is so close to the refractive index of the lens material, it is difficult for other optical methods to pick up the interface between lens and solution. Because of the high axial sensitivity of the confocal measurement method used in the instrument of this invention, there is generally no problem in making such wet thickness measurements.

The simplicity and sensitivity of the confocal technique, when used to make a differential thickness measurement, is such that the performance requirements of the optical system of the present invention are much simpler than those of a confocal microscope. Therefore, it becomes possible to construct the contact lens thickness meter without the need for a diffraction limited optical system. Unlike the confocal microscope, where image resolution is the ultimate aim, the use of diffraction limited optics may well present design problems in the present invention, as it limits the depth of focus to very small values, and also restricts the working distance. Both of these factors may make it more costly to provide control for the thickness meter, or make the instrument less convenient to use, both of which are advantages of this instrument over the prior art instruments. Therefore, within the limits of maintaining sufficient measurement accuracy, for the working distance and depth of focus required, in a further embodiment of the present invention, the focussing head is constructed specifically without approaching the diffraction limit of the optical system used.

Although the embodiments of the instrument of the present invention have been described above for the purpose of measuring the thickness of contact lenses, the method is universally applicable to the measurement of the thickness of thin optically transparent objects in general. In specific embodiments employing this method, the mechanical fixturing may need to be amended to suit the object whose thickness is to be measured, but the method remains basically unchanged. Depending on the accuracy and resolution required, the performance of the optical focussing system may also need to be improved to the optimum available.

There is therefore further provided, in accordance with another preferred embodiment of the present invention, a non-contact confocal method of measuring the thickness of thin optically transparent objects, comprising the steps of transmitting the illumination from a light source by means of an optical fibre to a focussing head, disposed so as to focus the end of the fibre onto the surface of the object whose thickness is to be measured. The light reflected from the surface of the object is

refocussed by the focussing head exactly onto the end of the fibre, which transmits the light back away from the end. A directional coupler disposed in the fibre diverts the returned light into a photo-detector, where it is converted into an electrical signal. The focussing head and the surface of the object are moved relatively to each other, either by moving the focussing head up and down, or by causing the object to move, or by means of moving both. A record is made of the relative positions of the focussing head and the object, when the detected reflected light signal shows the two maxima which occur as the focus moves through the top and the bottom surfaces of the object. The result, being the thickness of the object, is displayed, printed or stored by the electronic unit.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described hereinabove. Rather the scope of the present invention includes both combinations and subcombinations of various features described hereinabove as well as variations and modifications thereto which would occur to a person of skill in the art upon reading the above description and which are not in the prior art.

CLAIMS

1. A confocal thickness meter for thin transparent objects, comprising;

a source of illumination;

an optical fibre having first and second ends, said illumination being coupled into said first end ;

a focussing head, fixed to second end of said fibre, operative to focus said illumination from second end of said fibre, onto object whose thickness is to be measured, and to focus illumination reflected from said object back to said second end of said fibre;

apparatus for providing controlled relative motion between said object and said focussing head, along an axis in the direction of said focussed illumination;

a detector to detect maxima in the level of said illumination on reflection from a surface of said object;

a directional coupler disposed in said optical fibre for diverting illumination reflected from said object to said detector; and

an electronic unit for calculating and displaying the thickness of said object.

2. A confocal thickness meter for thin transparent objects according to claim 1, and additionally comprising mechanisms for providing controlled motion of said object in two orthogonal directions in a plane substantially perpendicular to the direction of the illumination, such that said illumination beam is scanned over the surface of said object, thereby providing a plot of the surface profile of said object.

3. A confocal thickness meter for thin transparent objects according to either of the above claims, and wherein said source of illumination is a laser diode.

4. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said second end of said fibre acts as a confocal pinhole

aperture, from which illumination diverges into the focussing head, and onto which illumination reflected from said object is focussed.

5. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said focussing head contains one convex lens for collimating illumination diverging from the end of said fibre, and one convex lens for focussing said collimated illumination onto said object to be measured.

6. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said focussing head contains one aspheric convex lens for collimating illumination diverging from the end of said fibre, and for focussing said collimated illumination onto said lens to be measured.

7. A confocal thickness meter for thin transparent objects according to either of claims 5 and 6, and wherein said lenses in said focussing head are of cast or moulded manufacture.

8. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said controlled relative motion between said object and said focussing head is provided by movement of said focussing head.

9. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said controlled relative motion between said object and said focussing head is provided by movement of said object.

10. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said controlled relative motion between said object and said focussing head is provided by movement of both said object and said focussing head.

11. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said controlled relative motion is executed by means of an electric motor.

12. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said illumination is maintained at a substantially constant DC level.

13. A confocal thickness meter for thin transparent objects according to any of the above claims, and wherein said illumination is modulated, and detection of said signal is performed by means of synchronous detection.

14. A confocal thickness meter for thin transparent objects according to any of the above claims, operative to measure the thickness of contact lenses, wherein said object is the contact lens whose thickness is to be measured.

15. A confocal contact lens meter, comprising;

a source of illumination;

an optical fibre having first and second ends, said illumination being coupled into said first end ;

a focussing head, fixed to second end of said fibre, operative to focus said illumination from second end of said fibre, onto said lens to be measured, and to focus illumination reflected from said lens back to said second end of said fibre;

apparatus for providing controlled relative motion between said lens and said focussing head, along an axis in the direction of said focussed illumination;

a detector to detect maxima in the level of said illumination on reflection from a surface of said lens;

a directional coupler disposed in said optical fibre for diverting illumination reflected from said lens to said detector; and

an electronic unit for calculating and displaying the thickness of said lens.

16. A confocal contact lens meter, comprising;

a source of illumination;

an optical fibre having first and second ends, said illumination being coupled into said first end;

a surface on which is disposed said contact lens;

a focussing head, fixed to second end of said fibre, operative to focus said illumination from the second end of said fibre, towards said lens to be measured, and to focus illumination reflected from the direction of said lens back to said second end of said fibre;

apparatus for providing controlled relative motion between said surface and said focussing head, along an axis in the direction of said focussed illumination;

a detector to detect maxima in the level of said illumination on reflection from a surface of said lens and from said surface on which is disposed said contact lens;

a directional coupler disposed in said optical fibre for diverting illumination reflected from direction of said lens to said detector; and

an electronic unit for calculating and displaying the sagitta of said lens.

17. A confocal contact lens meter, according to either of claims 16 or 17, operative to measure a contact lens while immersed in a solution.

18. A non-contact method for measuring the thickness of thin transparent objects, comprising the steps of:

transmitting illumination from a source by means of an optical fibre to a focussing head, disposed so as to focus illumination from the end of said fibre onto the object;

refocussing illumination reflected from a surface of said object by means of said focussing head onto the end of said fibre, which transmits said reflected illumination back up said fibre;

diverting said reflected illumination by means of a directional coupler disposed in the fibre, onto a photo-detector, for conversion into an electrical signal;

moving the focussing head and the object relative to each other, along an axis in the direction of said focussed illumination;

observing the relative positions of said focussing head and object when said detected signal shows the two maxima which occur as the focussed illumination moves through the top and the bottom surfaces of said object; and

multiplying the difference between said relative positions by the refractive index of said object, to give the object thickness.

19. A non-contact method for measuring the thickness of contact lenses, comprising the steps of:

transmitting illumination from a source by means of an optical fibre to a focussing head, disposed so as to focus illumination from the end of said fibre onto the contact lens;

refocussing illumination reflected from a surface of said contact lens by means of said focussing head onto the end of said fibre, which transmits said reflected illumination back up said fibre;

diverting said reflected illumination by means of a directional coupler disposed in the fibre, onto a photo-detector, for conversion into an electrical signal;

moving the focussing head and the contact lens relative to each other, along an axis in the direction of said focussed illumination;

observing the relative positions of said focussing head and contact lens when said detected signal shows the two maxima which occur as the focussed illumination moves through the top and the bottom surfaces of said contact lens; and

multiplying the difference between said relative positions by the refractive index of said contact lens, to give the contact lens thickness.

20. Apparatus according to any of the preceding claims and substantially as shown and described in any of the drawings.

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): G1A(AEXP, AEXS)

Int Cl (Ed.6): G01B(9/04, 11/06)

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X,&	GB 2 278 193 A (Hughes Aircraft) Whole Document	1-5,11,12 15,18,19 at least
X,&	US 5 483 347 (Hughes Aircraft) Whole Document	1-5,11,12 15,18,19 at least

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